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PULSED LASER DEPOSITION OF YBCO WITH YTTRIUM OXIDE BUFFER LAYERS (POSTPRINT)

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14. ABSTRACT

Textured metallic substrate based HTS coated conductors with the YBCO/CeO_2/YSZ/CeO_2/Ni architecture have already been shown to exhibit high current densities. The CeO_2 seed layer can effectively minimize the formation of NiO during the initial deposition on Ni and the CeO_2 cap layer provides good lattice matching to the subsequent YBCO layer. However, there are reports of cracks developing in the CeO_2 seed layer after a thicker growth due to a lattice mismatch with Ni, which can lead to poor performance of the YBCO conductor. The present work explores and alternate approach by using yttrium oxide not only as the seed layer but also as the cap layer in place of CeO_2. In the literature, yttrium oxide films grown on nickel by electron beam evaporation processes were found to be dense and crack-free with good epitaxy. This is likely the first report of using Y_2O_3 as a seed as well as a cap layer within the YBCO coated conductor architecture on specimens being fabricated in a single chamber. Pulsed laser deposition was used to perform deposition of all layers. Preliminary experiments resulted in specimens with current densities of more than 1 MA/cm^2 at 77K in self field. Characterization of samples was accomplished using x-ray diffraction, both resistive and ac susceptibility derived T_c, and J_c transport measurements.

15. SUBJECT TERMS

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ABSTRACT

Textured metallic substrate based HTS coated conductors with the YBCO/CeO_2/YSZ/CeO_2/Ni architecture have already been shown to exhibit high current densities. The CeO_2 seed layer can effectively minimize the formation of NiO during the initial deposition on Ni and the CeO_2 cap layer provides good lattice matching to the subsequent YBCO layer. However, there are reports of cracks developing in the CeO_2 seed layer after a thicker growth due to a lattice mismatch with Ni, which can lead to poor performance of the YBCO conductor. The present work explores an alternate approach by using yttrium oxide not only as the seed layer but also as the cap layer in place of CeO_2. In the literature, yttrium oxide films grown on nickel by electron beam evaporation processes were found to be dense and crack-free with good epitaxy. This is likely the first report of using Y_2O_3 as a seed as well as a cap layer within the YBCO coated conductor architecture on specimens being fabricated in a single chamber. Pulsed laser deposition was used to perform deposition of all layers. Preliminary experiments resulted in specimens with current densities of more than 1 MA/cm^2 at 77K in self field. Characterization of samples was accomplished using x-ray diffraction, both resistive and ac susceptibility derived T_c, and J_c transport measurements.

INTRODUCTION

Coated high temperature superconductors based on textured substrate technology are in the forefront of developmental efforts towards long length manufacturing of coated conductor tapes for practical applications.[1-3] Significant effort is focused on the development of new metallic substrates based on nickel alloys which are strong, non-magnetic, and are well textured.[4-6] At the same time, different combinations of buffer layers are also being developed to transfer the almost perfect cube texture in the metallic substrate to the $YBa_2Cu_3O_{7-x}$ (YBCO) layer epitaxially. Improvement of the in-plane alignment in the YBCO layer through a suitable seed layer on metallic substrates is an impotant aspect of the YBCO coated conductor development. The main considerations for the buffer layer are the lattice matching, thermal expansion coefficient matching, chemical compatibility, and ease of deposition.

Previously, a lot of developmental work has concentrated on the YBCO/ CeO_2/YSZ/CeO_2/Ni architecture which resulted in current densities exceeding 1 MA/cm^2 on samples.[7] The initial seed layer of CeO_2 has been very effective in preventing the formation of NiO, which might otherwise affect the epitaxy of subsequently applied layers. YSZ is a good diffusion barrier preventing the diffusion of nickel into the superconductor. A cap layer is deposited on YSZ to suppress the growth of $BaZrO_3$ at the interface between YSZ and YBCO. CeO_2 is a favored cap layer for YSZ due to its minimal mismatch with both YSZ and YBCO. Even so, interaction between the CeO_2 and YBCO layer may sometimes occur resulting in the formation of $BaCeO_3$ which can lead to a lower current density in the YBCO.[8] Also, the CeO_2 seed layer cracks after thicker growth due to the lattice mismatch with nickel.

Yttrium oxide (Y_2O_3) has a better lattice match with nickel and can reduce cracking problems. As such, yttrium oxide has successfully demonstrated replacement for the CeO_2 as the seed layer, alleviating the potential cracking problems even though CeO_2 is still preferred for the cap layer.[3] In the literature, there are successful reports of deposition of thick biaxially textured yttrium oxide layers on textured nickel by electron beam evaporation.[9] Ichinose et al. have described the process-related crystalline alignment and microstructure of Y_2O_3 buffer layers deposited under various deposition conditions by e-beam evaporation.[10] Paranthaman et al have deposited other buffer layers by sputtering on top of the yttrium oxide followed by pulsed laser deposition of the YBCO layer which resulted in high current densities (J_c ~1.8 x 10^6 A/cm^2).[11] The present work deals with yttrium oxide replacing CeO_2 as the seed as well as the cap layer. All layers, including YSZ and YBCO, are deposited in-situ in the same chamber by pulsed laser deposition.

EXPERIMENTAL

Textured nickel substrates were obtained from Oxford Instruments and the processing details have been presented elsewhere.[6] The substrates have an in-plane alignment of 7.2° FWHM and out-of-plane alignment of 8.4°. The various

oxide buffer layers and YBCO were deposited using pulsed laser deposition system in a Neocera chamber with a Lambda Physik (Model LPX 305i) excimer laser operating at the KrF wavelength of 248 nm. Specimens were fabricated to different stages in the YBCO/CeO_2/YSZ/CeO_2/Ni and YBCO/Y_2O_3/YSZ /Y_2O_3/Ni architecture to study the texture, smoothness and microstructure of the deposited layers. The background pressure in the chamber was brought down to < 10^{-6} torr pressure after mounting the specimens on the 2" diameter substrate heater. Specimens were then heated from room temperature to 750 °C in 180 mtorr atmosphere of Ar+4% H_2 (forming gas) gas mixture to prevent oxidation of the nickel substrate.

The layers were applied in-situ in the following manner. After a soaking period of 10 min, the Y_2O_3 (or CeO_2) seed layer was deposited at a laser energy of 625 mJ in the Ar+H_2 gas mixture for 3 min at a 4 Hz laser repetition rate. The laser spot size on target was 4.6 mm^2. The gas fill in the chamber was then evacuated and the chamber was pumped down to a pressure of 10^{-6} torr; the deposition of Y_2O_3 (or CeO_2) was continued for an additional 1.5 min. Oxygen gas was then introduced in to the chamber and after stabilizing the pressure at 10^{-4} torr, the Y_2O_3 (or CeO_2) layer was further deposited for 2 min. The temperature was then increased from 750 °C to 780 °C, and the YSZ buffer layer was deposited for 20 min in the oxygen atmosphere at a laser energy of 650 mJ using a 10 Hz frequency. A cap layer of Y_2O_3 was then deposited at a laser energy of 625 mJ and a 4 Hz repetition rate for 2 min. The oxygen pressure was subsequently increased to 600 mtorr and the superconducting YBCO layer was then deposited on the buffer layers.

The as deposited films were analyzed by detailed x-ray diffraction studies. Two theta scans were accomplished by using a Rigaku x-ray diffractometer. A Philips MRD with four circle diffractometry was used to study the crystalline alignment of the substrate, buffer layers, and the superconductor by means of omega, phi and psi scans. The microstructure of the various films was evaluated under scanning electron microscopy (SEM) to study the surface roughness and morphology of the film structure. Atomic force microscopy (AFM) was used to characterize the roughness of the buffer layers. The quality of YBCO was evaluated by x-ray scans as well as by ac susceptibility measurements to determine the critical transition temperatures (T_c's). Electrical property characterizations were made using a standard four-probe technique with a 1 μV/cm criterion to determine the critical current (I_c).

RESULTS AND DISCUSSION

The I-V plot of the current measured in the specimen RN-68 at liquid nitrogen temperature, representative of several good samples using Y_2O_3 as the seed and cap layer, indicated the specimen carried a critical current of 18 A which is equivalent to 1.2 MA/cm^2 of critical current density. Specimen RN-36 at 77K, representative of several good samples using CeO_2 as the seed and cap layer, carried an I_c of 15 A equivalent to a J_c of 1.0 MA/cm^2. Figure 1 shows ac

susceptibility data obtained for RN36 but is representative of both architectures indicating high T_c. The ac susceptibility plots of the YBCO specimen shown in Figure 1 exhibit an onset T_c of 90.1 K along with lower transition widths and peak shifts of the χ'' for varying magnetic field indicating strong inter-grain coupling and a potentially higher J_c.[12]

Thicker ceria seed layers induced cracking although yttria layers did not crack even as thickness increased. Figure 2 provides an image of the surface of the YBCO microstructure by SEM and AFM. The underlying grain boundaries of the Ni substrate are transferred to the final YBCO layer.

The x-ray theta-two theta scans on YBCO/Y_2O_3/YSZ/Y_2O_3/Ni and YBCO/CeO_2/YSZ/CeO_2/Ni as well as the intermediate buffer layers, showed sharp (00*l*) peaks indicating excellent c-axis texture in buffer layers which was carried over to the superconducting YBCO layer. Phi scans of the different layers on nickel indicate excellent in-plane alignment of the various layers although slightly better for the ceria architecture: YSZ = 8.3°, Y_2O_3 = 8.0°, and YBCO = 10° for the yttria architecture and for the ceria architecture CeO_2 = 6.7°, YSZ = 6.7°, YBCO = 7.1°. The FWHM of the buffer layers and YBCO did not change much from layer to layer indicating good epitaxy. Refer to Figures 3 and 4 for Psi scans of the two specimens. Figures 3 and 4 provide a comparison between the YSZ and YBCO layer of the samples.

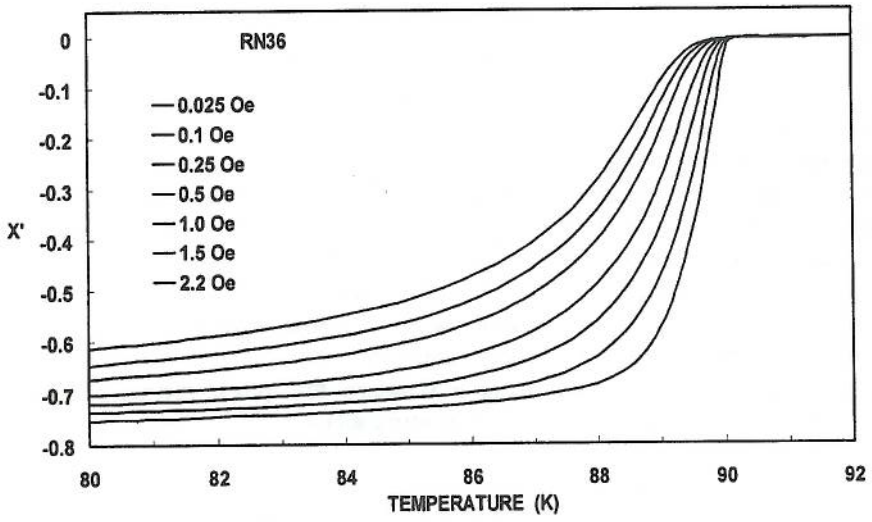
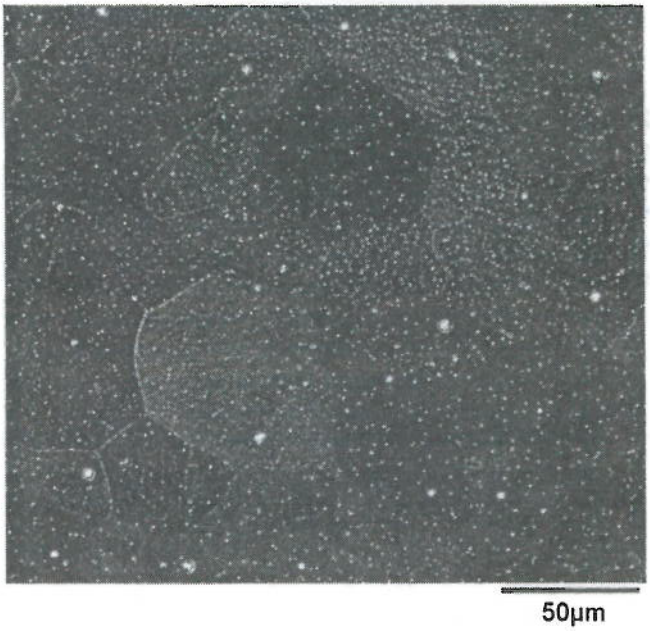
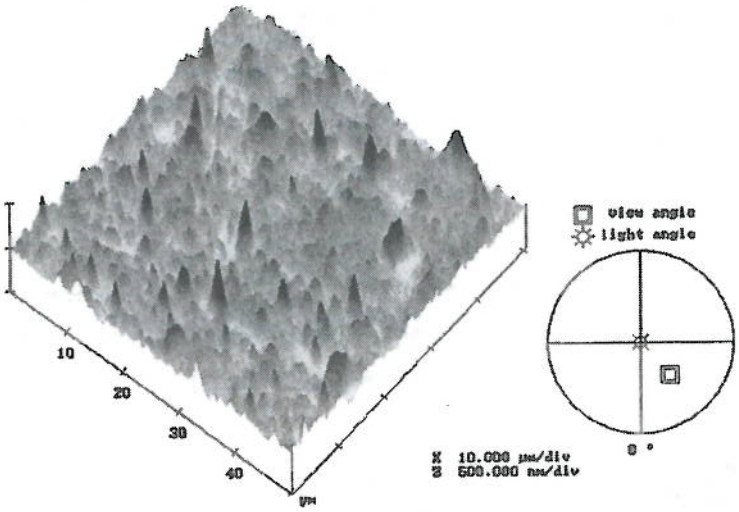


Figure 1. AC susceptibility data for the YBCO/CeO_2/YSZ/CeO_2/Ni architecture on a given sample. The different curves result from the different applied fields listed in the legend—the field increases from right to left.



(A)



(B)

Figure 2. YBCO layer on specimen RN-68: A) SEM micrograph displaying a large area of the surface microstructure, B) AFM picture showing the surface morphology of a 50 µm x 50 µm area .

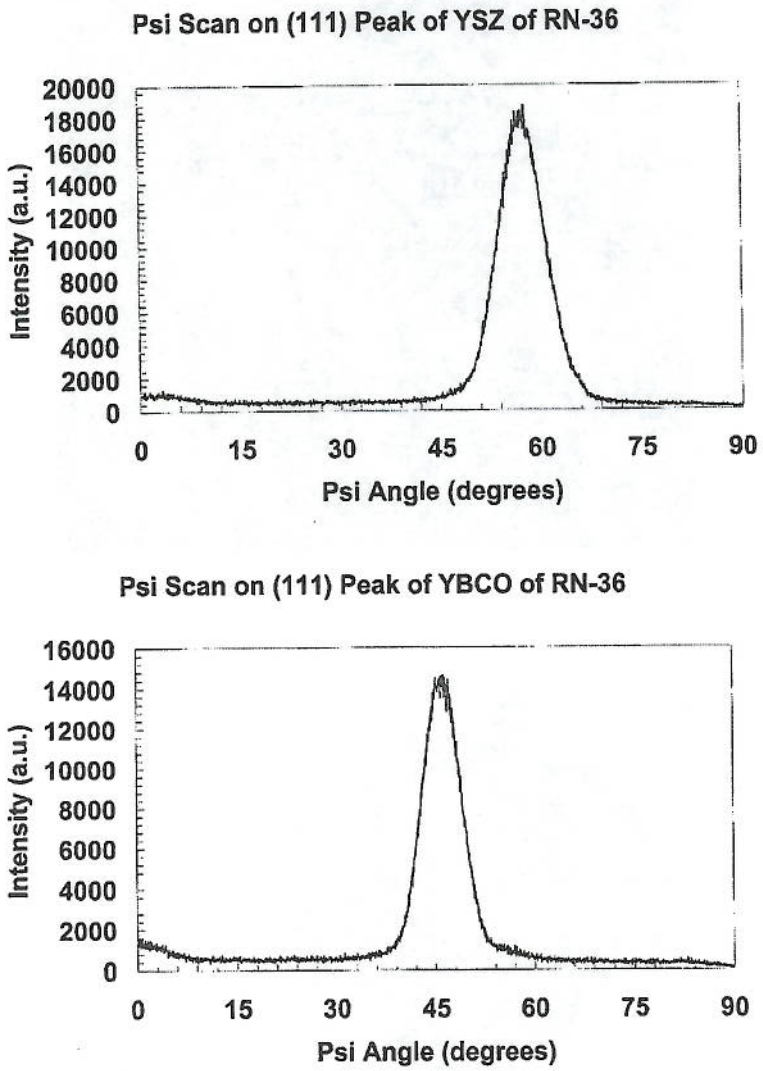


Figure 3. Psi Scan on (111) Peak of YSZ and YBCO layer of specimen RN-36 for the YBCO/CeO_2/YSZ/CeO_2/Ni architecture.

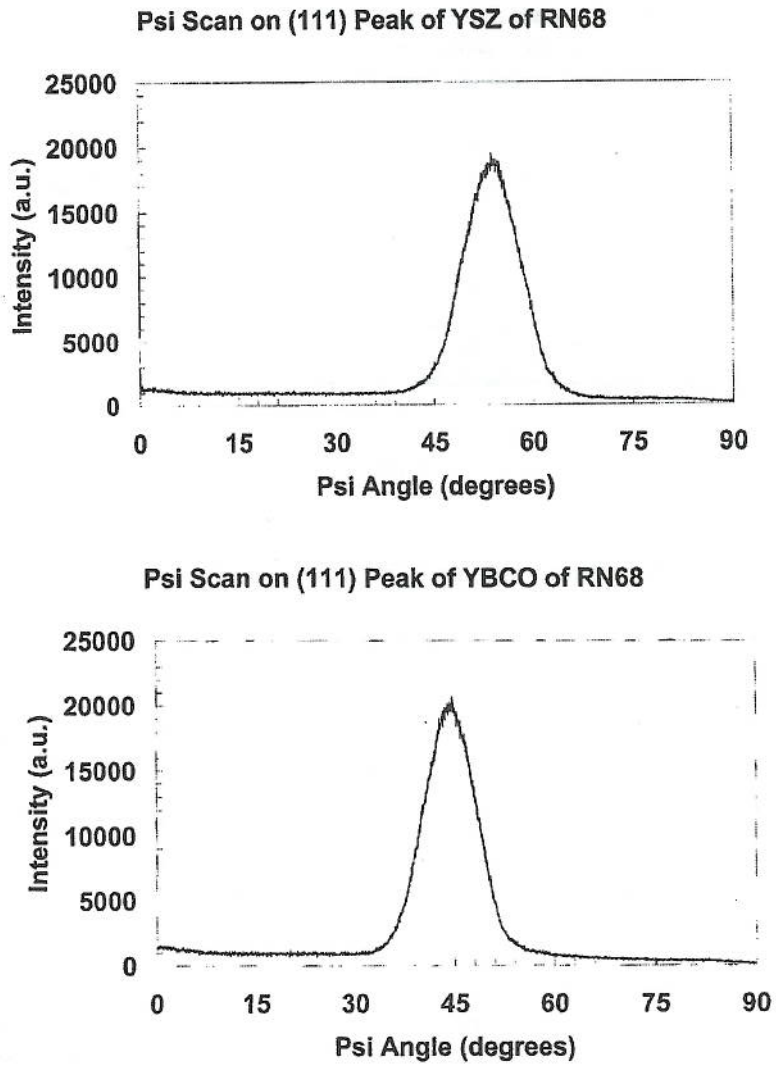


Figure 4. Psi Scan on (111) Peak of YSZ and YBCO layer of specimen RN-68 for the YBCO/Y_2O_3/YSZ/Y_2O_3/Ni architecture.

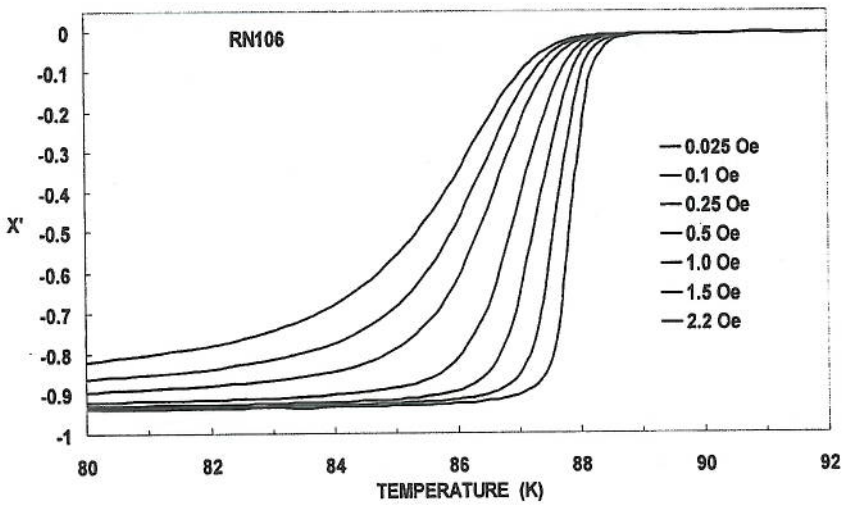


Figure 5. AC susceptibility data for the YBCO/Y_2O_3/Ni architecture for a given sample. The different curves result from the different applied fields listed in the legend—the field increases from right to left.

Additionally, a single buffer layer of Y_2O_3 applied to the Ni substrate was also experimented with. The ac susceptibility plots of the YBCO/Y_2O_3/Ni specimen showed a reasonable T_c (89 K onset) along with slightly broader transition widths and peak shifts of the χ'' for varying magnetic fields compared to those of the traditional YBCO coated conductor architecture. More work needs to be done to optimize the performance using a single Y_2O_3 buffer layer.

CONCLUSION

Yttrium oxide was successfully incorporated as both a seed and a cap layer in fabricating the YBCO coated conductor specimens on a textured nickel substrate in a single chamber using pulsed laser deposition. Good epitaxy was observed in all the deposited layers of the YBCO/Y_2O_3/ YSZ/Y_2O_3/Ni architecture leading to a high T_c (~91 K) and self-field J_c's of more than 1 MA/cm^2 on multiple samples. The microstructure of the yttrium oxide and the superconducting YBCO layers were dense, crack-free, and continuous with uniform coverage across the sample.

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